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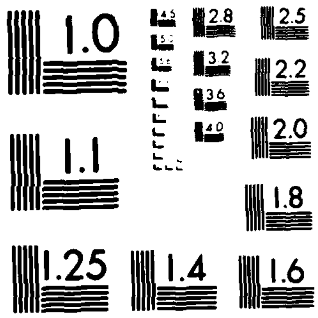
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MAN-MACHINE SIMULATION USING SADT(TM)/SAINT TECHNIQUES

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ABSTRACT

The U. S. Air Force is investigating analysis methodology and tools to use throughout the life cycle of various large complex man-machine systems. The simulation process is an important method for most life cycle stages but is often used with varying results. A solution for this problem is to develop and integrate tools for each phase of the simulation process. This paper reports on methods for integrating three phases: (1) Static system description, (2) man-machine performance data base development, and (3) Dynamic system description. SADT/SAINT techniques provide the integrating vehicle.

INTRODUCTION

Man-machine (M-M) modeling and simulation has been a neglected and often controversial discipline. Of the many possible reasons for this, two seem most prominent: 1) Historically the development of simulation languages were for queing and/or the machine aspects of systems, and 2) Human performance data base and taxonomy development has not been forthcoming. With the present increasing emphasis on M-M systems it is necessary to re-examine the methodology, tools, and techniques and improve existing ones or, possibly, develop and integrate new ones. This paper examines the M-M systems modeling and simulation process and describes the linking of SADT and SAINT, resulting in an enhanced total simulation capability that integrates the analyst, user and management.

Simulation techniques are used to model or duplicate the behavior aspects of a real world or conceptual system without using the actual system. The system life cycle can be broken down into stages or phases with each phase having a non-independent model. Models are descriptions of systems, and a simulation model can be considered as a laboratory version of a system [1] or simulation is experimentation with models [2]. Thus, simulation is a powerful tool for the study, analysis, and evaluation of various system life cycle phases. It is important to remember that models of the various phases may represent different viewpoints but by necessity must be consistent and have traceability between models. Also, a simulation model is usually derived from an existing life cycle phase model so the validity of results are a function of the mapping process. A top-down, structured, hierarchical approach is the bridge to a more objective and systematic methodology for simulation.

Structured Analysis and Design Technique (SADT) is a top-down structured technique for doing functional analysis and system design. It is particularly adaptable to M-M systems. System Analysis of Integrated Networks of Tasks (SAINT) is a simulation modeling and computerized modeling tool for application to large-scale M-M systems. This paper discusses the mapping of SADT models into SAINT models and the resulting advantages.

MAN-MACHINE SIMULATION PROCESS

The man-machine simulation process provides the capability to analyze currently existing and conceptual systems. This process is divided into six major activities (Fig. 1). The Describe System activity uses a system description technique to produce a static system model. The Generate Performance Data Base activity uses the static model as a guide to select the dynamic characteristics of the system. The Determine Simulation Objectives activity determines what is to be simulated within the system and the criteria for evaluating the system. The Construct System Simulation Model activity generates a dynamic system model from the static system model by using a simulation technique. The Exercise Model activity validates the dynamic model and the Run Experiments activity produces a proposed solution to the stated problem.

SAINT is a computer simulation tool for modeling and analyzing large scale, man-machine systems and is potentially applicable to a broad class of problems. SAINT fits into the simulation process as the simulation technique used to construct the system dynamic model. The SAINT program is the simulation program that executes on the computer and uses the dynamic model as input. Experience has shown, however, that the graphic network of SAINT models does not fully communicate a system description, system boundaries, and various levels of functional specifications. Thus, the Describe System activity is the weakest point in the simulation process.

To perform this activity, a systematic, highly structured, top-down technique is needed for performing and planning requirements definition, functional

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analysis, and system design. A comparison of methodologies, existing or under development, indicates that only SADT has the combined attributes for being applicable to requirements study of large complex systems [3].SADT is currently in use by the U. S. Air Force in the form of IDEF; it is thoroughly documented; it is easy to understand; and it provides the capability to model the resources in a man-machine system. Therefore, SADT was chosen as the system description technique used by the Describe System activity to produce the static model.

The resultant technique, SADT/SAINT, provides the capability to translate from one graphic technique to another, from one model to another, and from a static model to a dynamic model. The discussion presented here provides the reader with a brief explanation of how an SADT activity diagram communicates a system description, how a SAINT model is represented, and how to transition from SADT to SAINT.

An SADT model is a graphic representation of the system's hierarchic structure decomposed with a specific purpose in mind. A model is structured so that it gradually exposes more and more detail with the level of detail being dictated by the analysis requirements [5]. SADT uses a series of diagrams (figure 1 is an example) that define the system boundaries and illustrate the decomposition of the system structure in a top-down manner to the required level of detail. In order to provide a system description as a guide to creating a SAINT model, the system analyst develops an SADT activity (function) model.

An SADT activity model is an organized sequence of diagrams consisting of boxes (defining system activities) and of data arrows (defining relationships among the activities). The relationships, shown by the placement of the boxes and arrows, represent a description of the system for the reader.

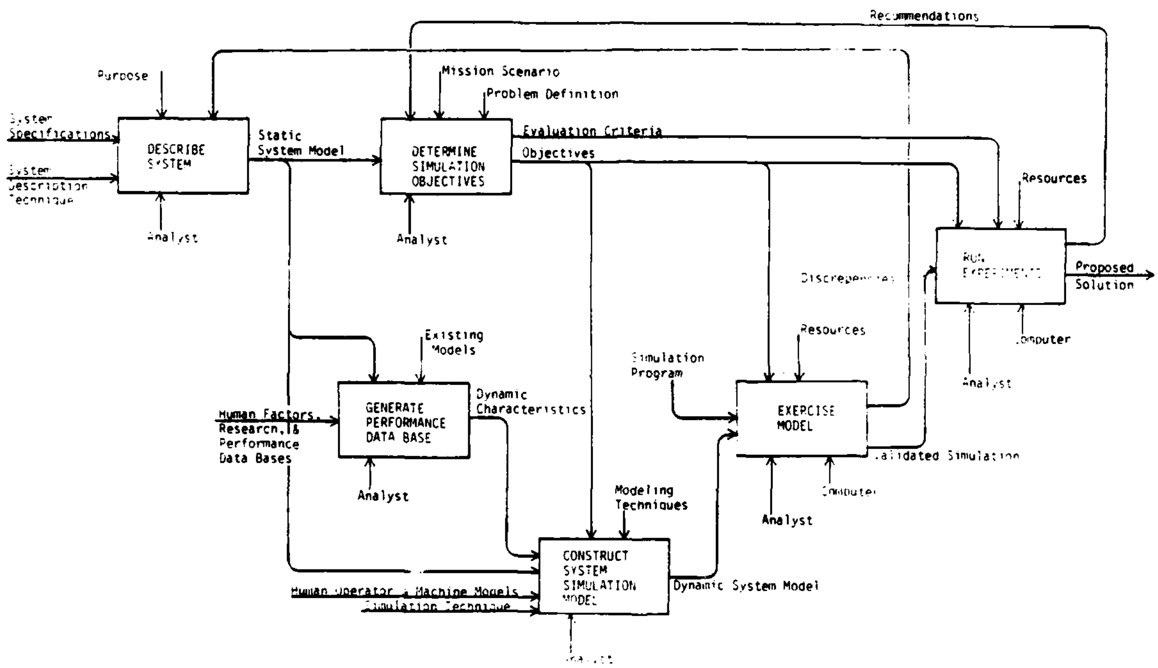

Figure 1. Man-Machine Simulation Process

SADT

SADT significantly increases the productivity and effectiveness of teams of people involved in a system project. Specifically, it provides methods for: 1) thinking in a structured way about large and complex problems; 2) working as a team with effective division and coordination of effort; 3) communicating analysis and design results in clear, precise notation, 4) documenting current results and decisions in a way that provides a complete audit of model design history; 5) controlling accuracy, completeness, and quality through frequent use of review and approval cycles; and 6) planning, managing, and assessing progress of the team effort [4].

The first diagram in a model is a single box that is a general description of the whole system. The general activity described by the diagram is further defined on the next diagram as three to six detailed activity boxes connected by arrows representing system data. This decomposition process continues until the system is described at the level of detail required.

The upper level, or less detailed diagram,defines boundaries for the lower level or more detailed diagram. The arrows around the box on the upper level diagram are the same as those entering and leaving the lower level diagram, i.e., the lower level is the same part of the same system in more detail (Fig. 2). The complete SADT model is a bounded representation of the system modeled from a given viewpoint and for a given purpose.

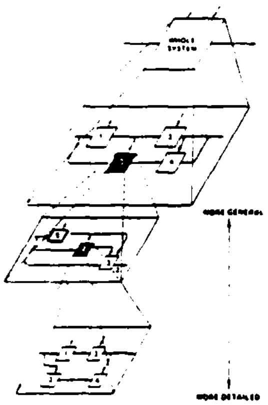

Figure 2. Structured Decomposition

The Author of SADT diagrams is responsible for studying a system and developing models based on SADT rules. He defines the orientation of the model by specifying the context, viewpoint, and purpose [5]. As the diagrams are developed, they are circulated for comments among individuals familiar with the system. The author updates and circulates the diagrams until they have been agreed upon and the required level of detail reached.

The SADT diagrams are easy to understand and can be used to communicate results to managers and technical personnel as the system is modeled. The final model report is published in an easy to read standard format that includes text and glossary of definitions. This report is a system description that is well coordinated, factual, and easy to communicate.

SAINT

SAINT is currently being used by organizations in industry, academia, and government to assist in the design and statistical analysis of complex man-machine systems. Models are synthesized using the SAINT symbol set and terminology resulting in a graphical network representation. These models are then exercised using the SAINT simulation computer program. SAINT, which has been alternately called a simulation technique [7], a tool [6], and a language [1], is potentially applicable to a broad class of systems in which discrete and/or continuous components and queues are portrayed that exhibit time varying properties. The history and evolution of SAINT may be found in [6].

Since SAINT graphical networks are synthesized, hierarchical modeling is an inherent aspect. A network task can represent a subsystem of the system structure or a network of tasks can represent the same subsystem. The graphic and hierarchical features help communicate and describe the system by showing criticality or priority, timing, precedence relationships and sequencing probabilities. This is lacking in many modeling and simulation languages for system description.

Two extremely important factors in the SAINT modeling approach are the system description and the modeler's experience, knowledge, and understanding of the system. The modeler uses the system description and SAINT symbol set to synthesize a model. Therefore, the simulation results are only as good as the system description. Realizing that the system description is also a model, the validity of the simulation results depend upon the purpose of both the descriptive model and the SAINT model and the equivalence of both. The importance of the system description is exemplified by the following excerpt:

> The level of detail at which a system or system segment should be modeled cannot be specified a priori. It is the analyst's responsibility to determine the level of detail to be included in the network model based upon the nature of the problem he is trying to solve and an analysis of the task components and their interrelationships. He must decide if it is sufficient to model a task as a single unit, or if it is necessary to model each component individually [7].

HUMAN PERFORMANCE DATA

While the SADT/SAINT combination is a powerful methodology for description and simulation of man-machine systems, the availability of appropriate human performance models and data can be an obstacle to efficient and timely application of the methodolgy. Because of its roots in task analysis and Monte Carlo simulation of human performance, SAINT requires an effective definition of basic operator tasks and appropriate estimates of performance time and error rate distribution parameters. Provisions are made for specification of factors which effect task performance (e.g., task type, operator skill level, system state, environmental conditions, etc.) and it is assumed that the modeler can provide descriptions of the functional relationships between conditions and parameters of interest. The lack of complete human performance data is not too critical when SAINT is being used for sensitivity testing. Human performance parameters can usually be estimated with sufficient accuracy to permit determination of critical areas in system design. However, if the primary concern is optimization, or refinement of system design, provisions for accurate representation of human performance is more critical and may necessitate the conduct of research over periods of time which contrast sharply with the fast-time capability promised by computer simulation techniques. Moreover, the combined costs of both data collection and simulation development may prove prohibitive in terms of resources allocated to the designing phase of system development.

There have been a number of attempts to establish a data base which would alleviate the human performance data problem for system simulation. For example, Meister [8], under U.S. Air Force sponsorship, did a study to determine the requirements and elements for human performance reliability data bank supportive of system development goals. Meister was challenged to extract data in a useful form from the larger variety of studies in the behavioral science literature. He developed criteria for the data bank and a taxonomy for classifying data and coded data from a sample of 140 studies. Meister concluded that the data bank was a feasible concept but required more work to make it practical including further taxonomy refinement, testing with a larger data base, possible reorganization to improve efficiency, and exploration of computerization. Meister [9] noted that the greatest hindrance to combining data from the general literature, was the lack of "standardized" methodology.

Another example of an attempt to develop a human performance data base with simulation support potential was initiated by Teichner [10]. Teichner sought a systematic approach to performance modeling, or prediction, as a function of task and environmental variables. He adopted an information processing approach to man-machine performance analysis and worked within a theoretical framework which related performance metrics to physiological processes which intervene between environmental input and human responses.

Defining operations on information within a man-machine component as "processes" and transfers of information between components as "tasks", Teichner identified four major task categories and five task activities which hold for any level of system description. The task categories are: machine-to-man, man-to-man, man-to-machine, and machine-to-machine. Task activities are: sensing, searching, coding, switching, and tracking.

Sensing involves the response of a sensor to applied energy. Teichner identified the sensory probability of detection, as the performance measures.

Searching is receptor-orienting or signal-seeking under conditions of sensor exposure to positionally different signal sources or to a single source at different times. Two performance measures were identified: search time and probability of detection.

Switching is simply a discrete action which changes the state of the next component in a sequence of system operations. Reaction time is the selected measure of switching performance.

Coding refers to the identification, or naming, of a detected signal. The measure identified is percent of correctly coded responses, or percent error.

Tracking consists of the alignment of a response with a varying input. Percent decrement in time on target, a relative measure, was selected as the metric since actual time on target depends on target width, etc., and must be determined uniquely.

Complex tasks involve various combinations of the five basic task activities. Examples offered by Teichner include handwriting, which is tracking combined with coding and tracking; and problem solving, successive coding plus coding and switching. Tasks, whether simple or complex, depend upon the same set of processes postulated by Teichner. Review of the processes is beyond the scope of this discussion. May it suffice to say that for human performance the processes are carried out within the central nervous system and derived from current research in neuropsychology.

Teichner's theoretical framework, task taxonomy and metrics served to guide the screening of the psychological and physiological literature for relevant data on human performance. Like Meister, he regarded his effort as no more than a feasibility study and, in fact, extracted data from a much smaller sample of the literature. Teichner emphasized that he had not explored the literature in sufficient depth to develop general relationships of the sort he desired. Nevertheless, Teichner's contribution is regarded as an invaluable complement to performance data base approaches exemplified by that of Meister. Teichner stressed the importance of being consistent with basic human performance theory; Meister placed primary importance upon meeting requirements of the system design process. Assuming that these two viewpoints are compatible, an integrated approach should produce an ideal model for a general purpose human performance data base.

Whatever the case may be, the potential payoff from man-machine system simulation and design effectiveness most certainly warrants renewed efforts to implement a computer-based human performance data bank which can be utilized for the SADT/SAINT technique.

SADT/SAINT COMBINATION

By analyzing the capabilities of SADT and SAINT, it becomes apparent that each fulfills a specific function within the simulation process. SADT is a technique for building a functional model to design, understand, communicate, and document the system. SAINT is a detailed, graphical network technique for building a simulation model containing the necessary input information for the SAINT computer program.

Translating between SADT and SAINT involves the identification of details related to the chronology of the SADT activities and associating them with the SAINT nomenclature. These details are available through the performance data base but a knowledge of SADT, SAINT, and the system must be available before an effective translation can be performed. It must be remembered that SADT and SAINT are methodologies for describing the system in a systematic, well-defined manner. They do not perform the system analysis; that must be done by the analyst.

Once the SADT functional model has been generated and agreed upon, it is used as a pattern for generating the SAINT simulation model and as a guide for generating the performance data base. The SAINT model includes the discrete task-oriented model, the user written routines and the continuous state variable equations.

The discrete task-oriented model is generated by translating the activities of the SADT model into the tasks of the SAINT flow network with each activity having a corresponding task. The SAINT tasks can represent different levels of detail.

By proper selection of the SADT activities, it is possible to have a detailed model for a part of the system and a general model for the remainder of the system.

CONCLUSION

SADT/SAINT provides the capabilities necessary to build a system simulation in a top-down structured manner, in a notation that communicates and documents the system, and in a form executable on a computer. The graphical notation of both techniques aids in the debugging, testing, modification, and communication of the system, and allows the various subfunctions of the system to be modeled at different levels of detail to meet the needs of the problem statement.

Significant efforts are needed to develop a comprehensive human performance data base supportive of

SADT/SAINT applications. The groundwork has been laid by a number of related research efforts, of which two were described briefly in this paper. Once standard requirements for such a data base have been established, inputs could be derived from a variety of applied behavioral research sources. Hopefully, interest in the benefits of SADT/SAINT and related computer simulation techniques will provide the incentive for a concerted effort to establish a common data storage and retrieval system.

Both SADT and SAINT are thoroughly documented and are being applied to large, complex systems. The SADT/SAINT combination currently requires no modifications to the individual techniques. To date, only a portion of the transition capabilities have been explored. However, as SADT/SAINT is applied to more complicated systems, additional transition capabilities will be realized and incorporated, possibly requiring minor modifications to the individual techniques. The resulting translation capabilities will bring out even more emphatically the powerful modeling and simulation capabilities possible with the SADT/SAINT combination.

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